

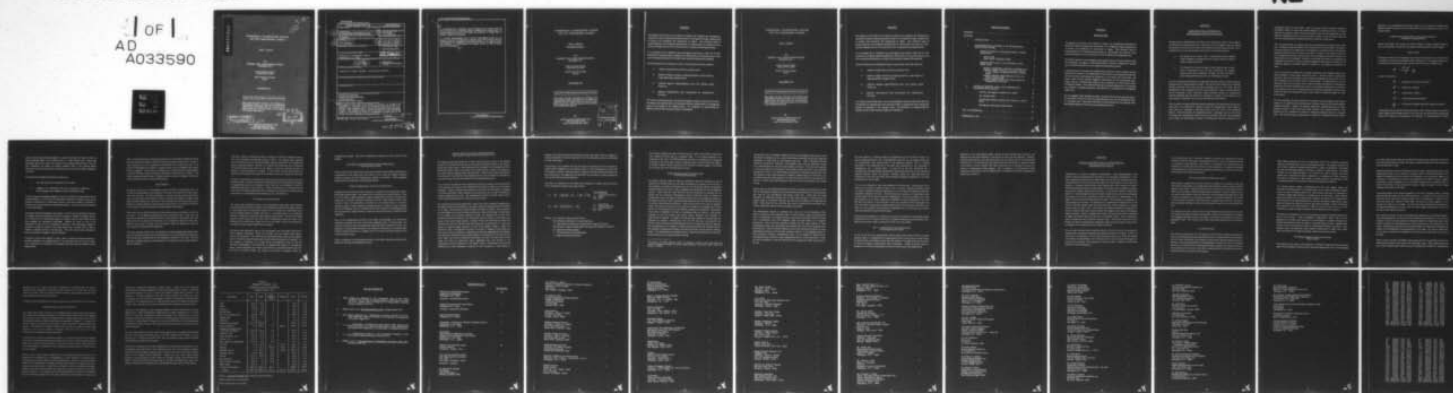
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INTERREGIONAL TRANSPORTATION ANALYSIS  
AND CIVIL PREPAREDNESS PLANNING

FINAL REPORT

For  
DEFENSE CIVIL PREPAREDNESS AGENCY  
Washington, D.C.

DCPA Contract Number  
DAHC 20-73-C-0203

DCPA Work Unit Number  
4335 B

NOVEMBER 1976

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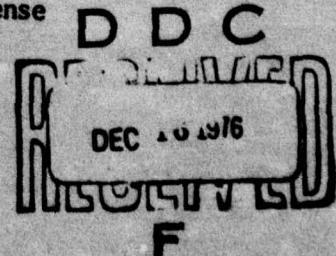
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✓ It is concluded that a feasibility type interregional input-output model has the best potential for analyzing freight transportation requirements in a recovery period as well as for analysis and projection of freight flows in general transportation planning.

It is further recommended that a two-tier interregional model be constructed, the first tier dealing with regional detail with provision made for linking second-tier subregional models (as available) to the regional model. The feasibility of implementing the regional model for BEA economic regions is investigated. ↗

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**INTERREGIONAL TRANSPORTATION ANALYSIS  
AND CIVIL PREPAREDNESS PLANNING**

**FINAL REPORT  
Detachable Summary**

**For  
DEFENSE CIVIL PREPAREDNESS AGENCY  
Washington, D.C.**

**DCPA Contract Number  
DAHC 20-73-C-0203**

**DCPA Work Unit Number  
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**NOVEMBER 1976**

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## SUMMARY

The purpose of this study is an attempt to evaluate the strengths and weaknesses of alternative models for generating requirements for interregional freight transportation in context with production and consumption by region. This evaluation leads to recommendations for modifying existing models to accommodate the needs for transportation analysis, both at the national level and in regional and subregional detail.

It is concluded that a feasibility type interregional input-output model has the best potential for analyzing freight transportation requirements in a recovery period as well as for analysis and projection of freight flows in general transportation planning.

Recommendations for modifying the model to more nearly meet these needs are:

1. measure transportation activities in physical units;
2. generate freight activities by applying distance of haul factors to origin-destination transport flows;
3. calibrate regional origin-destination data with national modal totals; and
4. generate region-specific input requirements for transportation activities.

It is further recommended that a two-tier interregional model be constructed, the first tier dealing with regional detail with provision made for linking second-tier subregional models (as available) to the regional model. The feasibility of implementing the regional model for BEA economic regions is investigated.



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## CHAPTER 1

### INTRODUCTION

The purpose of this study is an attempt to evaluate the strengths and weaknesses of alternative models for generating requirements for interregional freight transportation in context with production and consumption by region. This evaluation leads to recommendations for modifying existing models to accommodate the needs for transportation analysis, both at the national level and in regional and subregional detail.

This report focuses on the interregional input-output model as the most practical model for the purpose, and suggests modifications needed to facilitate transportation analysis and to maintain consistency between regional and subregional models.

A previous report (5) described the transportation networks in detail, evaluated existing transportation models for their applicability to the needs of civil preparedness planning, and recommended modifications and extensions to more nearly meet these needs. The present report further describes suggested modifications of the interregional input-output model as a feasibility type model for use in planning for a recovery period after a widespread disaster. The model described also has general application to the analysis and projection of regional production, consumption, and interregional and intraregional freight flows.

The interregional model described provides a national (and broad interregional) analytical framework to which the local civil preparedness planner can link subregional detail for his specific area. This permits flexibility in decentralizing the local planning while maintaining consistency with the national planning objectives.



## CHAPTER 2

### TRANSPORTATION ACTIVITIES IN AN INTERREGIONAL INPUT-OUTPUT MODEL

Transportation is represented by activities in the input-output model, in most respects not unlike other economic activities. It has inputs of fuels, supplies, labor and capital and produces a service which is "sold" to intermediate and final demand sectors. Yet it is different from most other economic activities in two principal respects:

1. the demand for its output "sold" to intermediate sectors (largely freight transport) is largely derived in unique relation to specific inputs to these sectors; and
2. the demand for the above freight services depends upon the patterns of interregional trade, and input coefficients for transportation services may be expected to change over time with shifts in these trading patterns apart from any technological change.

The first characteristic noted above is significant because it places a large demand for detailed data for implementing the model. Not only are data needed on the transport services associated with each commodity producing sector in the model, but also separately for each consuming sector for each commodity. This is so since different sectors consuming a given commodity require different amounts of transportation services depending upon the location of the plants in relation to the location of the input supply (a consequence of the second characteristic noted above).

Thus, in order to develop coefficients representing inputs of transportation services into each sector, it is necessary to compile a matrix of transportation service inputs in which each row represents a commodity (input) and each column the "purchasing sector." After this matrix of transportation data is developed, and the row totals reconciled with transportation modal controls by commodity, the rows may be collapsed into a single row representing the input of transportation services (combined for all

commodity inputs) into each sector. Since the control totals on transport haulage by commodity referred to above are available separately by mode (rail, water, air, truck, pipeline) the rigorous method involves developing these matrices separately by mode and then collapsing the rows in each matrix into a single row for each mode, each such final row representing the transportation service inputs for a given mode.

The very detailed data on transport services as outlined above are generally not available. Transport modal data provide tons, revenues, and for some modes, ton-miles by commodity group but not separately by "purchasing" or consuming sectors. The data are generally collected from the carriers who report the data to the regulatory agencies from waybill records which contain the name of the consignee as well as the data on the characteristics of the shipment. However, no provisions are made for classifying the consignees by industry or sector and reporting aggregate modal data in this detail to the regulatory agencies, presumably because it would be a very expensive compilation to make.

In view of this lack of detailed data on freight purchases by each consignee industry, the usual procedure in input-output models has been to allocate freight transportation associated with each commodity to each industry purchasing that commodity more or less in proportion to the volume (value) of the purchases. If transportation is to be so allocated, much time and effort can be saved by simply allocating the transportation associated with each commodity as an input to the industry producing the commodity. In the solution to the set of simultaneous linear equations comprising the input-output model, the results are exactly the same in this method of allocating freight as in the other method.

The first procedure has been followed in developing most interregional input-output models but the coefficients so developed have not been reconciled with actual regional transport activities. Rather, the national coefficients representing inputs of transportation services to each sector have been imputed to the regional sectors. This obviously is not a satisfactory method for calculating transport needs on a regional basis. This method misses an opportunity to utilize the interregional shipment detail

generated in the interregional input-output model to more accurately calculate both regional transport needs as well as the national total of such needs (as the sum of the regional detail).

### ALTERNATIVE MODELS FOR CALCULATING REGIONAL TRANSPORT REQUIREMENTS

Several input-output type models have been developed to project regional output by sector and, implicitly or explicitly, the transport commodity flows between regions.

#### Gravity Model

The gravity version of the interregional input-output model assumes that trade between two regions is a function of attracting masses, production in the originating region and consumption in the destination region, and an inverse function of transport costs:

$$X_i^{gh} = \frac{X_i^{go} \cdot X_i^{oh}}{X_i^{oo}} \cdot \frac{1}{d_i^{gh}}$$

where, for commodity i:

$$X_i^{gh} = \text{shipments from region g to region h}$$

$$X_i^{go} = \text{production in region g}$$

$$X_i^{oh} = \text{consumption in region h}$$

$$X_i^{oo} = \text{total production (consumption)}$$

$$\frac{1}{d_i^{gh}} = \text{a function of transport costs from region g to region h.}$$

The problems with the gravity version are several. First, the above system of equations cannot explain actual transport flows to the extent they are determined by institutional factors not reflected in the equations. For example, if a receiving region is located



nearby several large producing regions of a given commodity, the flows in from the given producing region will be different than if it were located near a single large producing region (of the same size as each of the producing regions above). Thus, the "d's" incorporate the effects on specific transport flows of the existing spatial distribution of plant location which is determined by many factors besides transportation costs.

The presumed advantages of the gravity equation are:

1. the trade flows may be estimated in lieu of data;
2. changes in the coefficients (d's) may be projected in response to known changes in the transport network and transport costs.

The first presumed advantage disappears if the d's are affected by institutional factors as discussed above. If the d's are not consistently functions of transport costs but are affected differentially by institutional factors, trade flows cannot be derived by estimation but must be based on empirical observations. The d's are then derived based on these observations.

The second presumed advantage is also illusory. If the d's are not consistently functions of transport costs, then projection of the d's in response to changes in transport costs is not a simple matter of estimating changes in transport costs on each modal link and then changing the coefficients accordingly. Instead, all other d's have to be recalibrated so that the set of equations is satisfied. This recalibration requires a projection (outside the model) of the actual trade flows, the same kind of data as required to calculate the d's in the base year. Thus, the model structure provides no help in projecting the changes in these coefficients.

The gravity model is also difficult to solve. Since it contains non-linear equations, it has been necessary to use approximations of the non-linear terms in the set of equations. This gives rise to problems of convergence which have not been resolved for any large systems.

Tests of the performance of the gravity model versus a fixed import coefficient version for small systems have shown no greater accuracy for the gravity version (1). In view of these results and of the computational complexities of the model with none of the presumed advantages being realized, a simpler version of the interregional input-output model is suggested. This version is the fixed import coefficient version which appears to perform at least as well as the gravity version but is much easier to compute. This version is discussed further below. However, another version of a regional input-output model, the Harris version, is first examined below.

#### Harris Model (2)

The Harris version is not an interregional model, and trade or transportation flows are not derived simultaneously in the model (as in the case of the gravity and fixed import coefficient versions). The Harris procedure is to project national sector output levels using a national input-output model and then to impute sector outputs to regions using regional-share equations for each sector. These equations are fitted historically and are designed to explain changes in regional shares for each sector as a function of variables which capture the relative production cost advantages of each region.

Trade flows are not derived implicitly in the model but may be estimated in either of two ways: (1) by applying interregional trade coefficients from a base year and iterating the results until consistency between the production, consumption, and trade flows in and out is achieved for each region, or (2) solving the system for least cost-transport flows, given transport costs by regional origin and destination, using the linear-programming transportation algorithm.

The latter approach suffers from the limitations of linear-programming solutions generally in that product detail has to be extremely fine to avoid unrealistic solutions and that institutional considerations are not adequately reflected in the costs. The first approach is probably superior to the second, but is cumbersome and also yields results of dubious reliability.



The Harris model is an admirable attempt to bring in the effects of regional comparative cost advantage in determining industry location. The regional share equations contain variables aimed at reflecting relative regional production and transportation costs on inputs and outputs. However, it is doubtful that these costs can be quantified in sufficient detail for all sectors in all regions to make the resulting estimates of change in industry location very reliable. It is not known to what extent Harris has tested the performance of the model since his publications do not discuss any such tests.

Criticism of this model or the gravity version does not imply that there is any more accurate model. The state-of-the-arts in modelling economic development (and changes in supply/demand locational patterns) is very weak and the availability of data to implement such models is very limited. In these circumstances it is the belief of the author that more simple approaches which incorporate structural detail (which provides some stability in the locational relationships) are more cost effective.

#### Fixed Import Coefficient Model

The fixed import coefficient version of the interregional input-output model assumes that requirements for each commodity in each region are supplied from regional sources in fixed proportions, the proportions being fixed by the base year observations which may be adjusted based on updated information. In practice there is no systematic method for updating or projecting these regional trade patterns. Therefore, the model projects regional production and trade flows simultaneously under the rather naive assumption that imports into a region from each other region remain a fixed proportion of consumption plus foreign exports from the region.

This rather naive assumption may be the best possible under the present state-of-the-arts in regional forecasting. There is no evidence that other models yield superior results, or even as good. This version of the interregional input-output model is appealing in its relatively simple computational requirements and flexibility for updating. It is also feasible to implement it in enough sector and geographic detail so that the structural relationships in the model can be observed and analyzed in considerable detail. Skillful delineation in the sector classifications of commodities which constitute the bulk of intercity freight can provide even greater meaningful detail for



transportation analysis. This latter consideration is explored in a later section of this chapter.

### SUGGESTED IMPROVEMENTS TO THE INTERREGIONAL INPUT-OUTPUT MODEL

There are four major improvements which may be made in the present formulation and computations of the model which will render it more useful for regional economic analysis in general and for transportation analysis in particular. These suggested improvements are described in the following sections.

#### Measure Transportation Activities in Physical Units

Transportation activities have been measured in revenues in the national and interregional input-output models. This measure is not satisfactory for several reasons. First, it is much easier to apply modal-split models to freight flows measured in physical units rather than in revenues. Secondly, coefficients for fuel, repair parts and many other important inputs to transportation activities are more stable based on a physical measure of output. Finally, measures of physical units for a number of modes, including most private haulage, are more available than revenue measures; for modeling purposes the more accurate measures should be used and revenue estimates as desirable made separately.

Most of the transportation activities, both freight and passenger, are conveniently measured in physical units such as ton-miles, passenger-miles, or vehicle-miles. Receipts for minor services and miscellaneous operations may be measured in value if it is important to include these activities in the model (an alternative is to estimate these receipts outside the model in a constant ratio to the main activities included in the model for a given mode).

There is no problem in incorporating activities in the model measured in physical units along with other activities measured in value.

### Generate Freight Activities by Applying Distance of Haul Factors to Origin-Destination Transport Flows

The regional origin and destination of each commodity flow is given in the diagonal elements of the trade flow matrices in the column coefficient version of the interregional input-output model. These coefficients may be applied to the consumption levels by sector by region which are an output of the model solution, to derive the quantity of each trade flow by regional origin and destination. Factors which reflect the approximate distance of haul between each regional pair may then be applied to estimate the ton-miles required for each commodity flow by origin-destination pair.

It is convenient to generate these transportation activity measures (ton-miles) directly in the model so that inputs to the transportation activities by region can be accurately calculated. Thus the transportation equations in the matrix for each region are changed to include coefficients which represent the ton-miles per ton of each commodity by regional origin-destination pair. The transportation columns will then contain coefficients representing the inputs by mode per ton-mile of haul.

The transportation activity generated by region must reflect shipments originating in the region, shipments terminating in the region, shipments originating and terminating in the region, and shipments passing through (traversing) the region. Since shipments into each region from any other region are always a constant percentage of consumption in that region in the column coefficient model, the transportation activity (row) coefficients would be attached to the consumption activity measure in each region (the region at hand and all other regions). In order to derive the coefficients the base year transportation flows by regional origin-destination pair are distributed in a base year matrix by region-to-region segments so that flows passing through a region are identified as such. The appropriate amount of ton-miles is assigned to each region for each type of flow by commodity: originating, terminating, originating and terminating, and traversing. Since all flows are linearly related to consumption of the commodity in some region, the ton-mile coefficients associated with each commodity flow in each region are sorted by destination region, aggregated and then entered in the transportation activity equations for the region at hand. Theoretically, there will be coefficients for each consumption variable for each commodity in each region; in



practice there will be many zero coefficients since each region will not originate or terminate shipments to all other regions nor will it be traversed by all flows terminating in every other region.

Unfortunately, this procedure has the same type of complexity as the transportation margin matrix assignment in the national model (in which transportation coefficients are assigned to specific consuming sectors). However, the added regional dimension has been incorporated. The assignment of coefficients can be done by a computer algorithm once the data base has been established.

The system of equations for the model with transportation freight activities derived from interregional transport flows is given below:

		<u>No. of Equations</u>
(1)	$X_i^g =  A_i^g   X^g  + Y_i^g + \sum_h T_i^{gh} - \sum_h T_i^{hg}$	$\begin{array}{l} i \\ g \\ \hline i \cdot g \end{array}$ <div>commodities (sectors) regions total</div>
(2)	$T_i^{gh} = F_i^{gh} ( A_i^h   X^h  + Y_i^h)$	$\begin{array}{l} i \\ g \cdot h \\ \hline i \cdot g \cdot h \end{array}$ <div>commodities transport flows for each commodity total</div>

Notation:  $X$ , production;  $|X|$  production vector  
 $|A|$ , technical coefficient row vector (specified)  
 $Y$ , final demand including net foreign exports (imports)—specified  
 $T^{gh}$ , domestic transport freight flows (ton-miles) from region  $g$  to region  $h$   
 $g, h$ , superscript denoting region  
 $i$ , subscript denoting commodity group  
 $F$ , freight coefficient (specified)



The transport freight flows may be broken down by mode in the model or projected in total, making the modal split in a separate model. If the modal breakdown is incorporated in the model, the  $F_i^{gh}$  coefficients will have to be changed if the modal split is revised. If the modal split is done in a separate model, the input coefficients ( $a_{ij}^g$ ) for the freight transport activity will have to be revised to reflect changes in the modal mix by region each time the modal split is revised.

#### Calibrate Regional Origin-Destination Data with National Modal Totals

The freight transport flows by origin and destination should be reconciled as far as possible with national totals for ton-miles as available from reports of the carriers to the Interstate Commerce Commission and the Civil Aeronautics Board, the published waterborne data by the Army Corps of Engineers, and estimates for the non-regulated carriers. These totals are more accurate than can be obtained by summing the rail waybill and the Commodity Transportation Survey (CTS) data from the Census of Transportation which are based on samples and also do not have complete coverage (the rail waybill covers only Class I railroad carload shipments and the CTS data are limited to domestic manufacturers' shipments). There are no waybill (O-D) data for pipelines except the broad O-D data given by the Bureau of Mines<sup>1</sup>, and reconciliation of these flows with the totals given by the Oil Pipeline Association is appropriate. Unpublished Army Corps of Engineers O-D data on waterborne ships are based on 100 percent coverage of both commercial and private carrier shipments and therefore no reconciliation is required. Air freight O-D data are only available on a sample basis for shipments by domestic manufacturers from the CTS data and reconciliation with national totals (reported by individual airlines but with no commodity detail) is required. The trucking data are the weakest; national totals by commodity are available only for ICC regulated trucking which accounts for about 35 percent of total intercity trucking freight. O-D sample data are available only for manufactured products from the CTS but include both commercial and private trucking.

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<sup>1</sup>The Bureau of Mines reports crude oil shipments state-to-state and petroleum product shipments between Petroleum Administrative Districts (PAD) which are groups of states.

The previous work on transport freight flows for the interregional input-output model attempted to develop flows on a state-to-state basis reflecting the ultimate origin and destination of these flows by the principal mode only. Thus, intermodal shipments (truck-rail, truck-water, rail-water, truck-pipeline, etc.) were not identified; neither were transshipments via the same mode explicitly identified. The flows were measured in tons and could not be reconciled with national modal data due to the extensive duplication of tons in the national data resulting from intermodal shipments (the tons are reported by each mode carrying the freight on separate legs of a total haul). Reconciliation may have been possible if the data had been converted to ton-miles but the failure to identify intermodal shipments would have made this procedure very tenuous at best.

Recent work for the Transportation Systems Center involving the development of a data base on interregional shipments of bulk commodities holds promise for a much improved data base for the interregional input-output model work. These data are being developed for shipments between the 173 BEA areas (groups of counties) and the separate legs of intermodal shipments are identified as separate O-D shipments by mode. These data then are such that they can be compared (and reconciled) with national modal data reported for tons hauled by commodity.

The transshipment problem is a difficult one to deal with in an interregional model linked to production and consumption data in which ultimate origins and destinations need to be identified. The inherent problem is that certain commodity shipments funnel into a transshipment point from separate origins and then funnel out to separate destinations. Some commodity shipments literally lose their origin identity at these transshipment points, e.g., grain going into elevators and oil into main pipelines from gathering lines. Other commodity shipments do not lose their physical identity at these transshipment points but still lose their statistical identity. In the aggregated data for these shipments entering a transshipment point, it is not possible to identify which incoming shipments constitute a given outgoing shipment to a final destination. It may not even be desirable to make this identification for purposes for which the data are to be used.



The only solution, if ultimate origins and destinations are to be directly linked, is to prorate outgoing shipments from a transshipment point over all the origins feeding into the transshipment point proportionate to the respective volumes. This is a logical assumption in any analytical use of the data (e.g., projections) if the commodity is homogeneous, e.g., a specific grain. It may not be the best assumption for a heterogeneous commodity group since specific origin-destinations may in fact distinguish separate products within the groups. However, unless the commodity-flows are constructed in very fine commodity detail (literally thousands of products) it is the best assumption that can be made.

It may not be desirable to make such prorations in the data base. The data base can be related more directly to modal O-D data if this is not done. Keeping the original modal O-D detail will greatly facilitate adjustments to the data based on improved modal data and general updating of the data. The modal flows may be shown in the data base as they actually occur with no specific links for transshipments. The amount shipped into a node plus production at the node is balanced by shipments out plus consumption in the node. The links are implicit. If the data base is cast into a model in which requirements for each commodity in each node are drawn proportionately from all sources, the effect is the same as if the proration were explicitly incorporated into the data base and ultimate origins and destinations were directly linked.

The potential development of a complete data base in this detail for interregional freight shipments and how it would be fitted into a production/transportation/consumption inter-regional input-output model is described in detail in the next chapter.

#### Generate Region-Specific Input Requirements for Transportation Activities

In view of the fact that transportation activity levels would now be derived in modal detail by region, it is appropriate that region-specific data on fuels, labor and other inputs be derived based on available regional data and related to the appropriate activity levels to derive the regional transportation input coefficients. Freight activities would be measured in ton-miles and passenger activities in vehicle-miles or passenger-miles.



Heretofore in the interregional models, non-commercial trucking, general aviation, and business auto have been subsumed in the sectors in which they are operated. Similarly, personal and government auto and aviation have been included as part of the final demand requirements. It is recommended that these activities be established as separate sectors in the model in order to identify their inputs separately and to facilitate the use of the model for transportation energy analysis. This is analogous to the treatment of these transportation activities in the U.S. Department of Transportation national transportation input-output model (4).

### CHAPTER 3

#### INTERFACE BETWEEN LOCAL AND INTERREGIONAL TRANSPORTATION MODELS

Transportation by nature is regionally interdependent. This interdependency is tied closely to economic production and consumption, also regionally interdependent. However, transportation needs within a region depend not only upon the capacity required to transport goods in commerce between the region and other regions, but also upon that required to transport goods between other regional pairs which traverse the region. This latter phenomenon places an added degree of complexity on interregional economic models which include transportation activities. In the previous chapter a method was outlined for deriving region-to-region transport freight flows within the interregional input-output model so as to generate the input requirements to transportation in the region in which the actual transportation took place. This procedure is cumbersome in implementing the data base. An alternative is to generate the transport flows in the model by ultimate regional origin and destination only, without assignment to regions through which the flows move. These flows would then be assigned to transportation routes in another model which would also make the assignments by region, including the regions traversed. Inputs to transportation freight activities would then be calculated by region and entered back into the main interregional model. These requirements would then generate some additional transport flows. Total flows would then be run through the separate transportation assignment model and the procedure iterated until convergence was reached (within two or three iterations).

The procedure described above would definitely be the one to follow if an analysis of transportation routings and transportation capacity limitations is desired. If this is a focal point of the analysis it must be done separately in any event. Since this analysis may develop routings different from the base year, it should be taken advantage of in improving the accuracy of the results from the main model. Therefore, the iteration procedure would be appropriate.

It was stated above that it would be necessary to perform any transportation routing analysis outside the main model. Theoretically this is not true, but for practical reasons it is deemed the best approach. This leads into a discussion of the practical size and complexity of models and the needs for two-tier approaches in handling interregional interdependencies among production/transportation/consumption activities with interfaces between local and national models.

### Two-Tier Interregional Transportation Models

Theoretically, transportation activities could be included in an economic model with fine sector and area detail, with origin-destination transport routes by mode as specific outputs of the model. Capacity constraints could be attached to each transport link in order to use the model to identify transportation bottlenecks. The more simple form of the model would assume a base year modal split and interregional routings, and be used to assess the feasibility of meeting the transport requirements generated in the model. A more complex formulation would employ linear programming to make the modal splits and interregional routings in an optimum fashion given transport costs and capacities by link.

The problem with such a model is that it would require excessive computer time, even with present day large computers, and generally would be too cumbersome to manage. This suggests breaking the model into stages, each stage concentrating on one level of geographic detail. Two models of this nature have been proposed and are discussed below.

### The Pearsall Model

This model was proposed by Dr. E.S. Pearsall of the Institute of Defense Analysis as a means of decentralizing economic planning activities to a regional basis in a post-attack economy while maintaining interconsistency among these regional planning activities. However, the interregional economic interdependencies (trade flows) were not explicit variables in the model and thus interregional freight transportation requirements could not be generated in the model. This model is discussed simply to illustrate one type of interface between national and local planning.





Each regional planning unit has an input-output model with resources (production capacity, inventories, labor, etc.) and technology specified. The planner optimizes the use of these resources to produce goods needed to sustain the population in his region and uses any remaining capacity to produce for export to other regions. The payoff function for each regional planner is to minimize the value of imports from other regions and to maximize the value of exports (i.e., to maximize net value of exports). Net exports are allocated to other regions to sustain survival of the population or used in advancing recovery by investment in facilities throughout the economy.

The national planner obtains a preliminary plan from each regional planner and evaluates the national picture in a national model. In this model he calculates "shadow" prices for each commodity based on the total national needs and the imbalances in commodity supply/needs derived by summing all the regional plans. These "shadow" prices then become the unit values placed on exports and imports in the regional plans. They are given to the regional planners who redo their calculations using the new values placed on imports and exports and revise their plans accordingly. These revised plans are evaluated by the national planner to derive a new set of prices, and so on until consistency between the regional plans and the national objectives is achieved.

This model has considerable merit for coordinating post-disaster production planning for survival and recovery. Since interregional transportation freight flows are not generated in the model these would have to be developed in a separate transportation model which allocated exports by region to importing regions through a transportation network so as to minimize costs within the transportation capacity constraints. These transport flows would generate further resource requirements by region which would have to be iterated in the regional planning models and the national model.

#### The Multiple Resource Location and Allocation (MRL/A) Model

The essence of this model is the allocation of national (or regional) production requirements to surviving plant locations so as to minimize transportation costs. The formulation

is a linear programming model with production technology, plant capacities and required final deliveries specified by region, and region-to-region transportation links, capacities, and costs specified by mode.

National production levels are calculated by sector, using a national input-output linear programming model, so as to achieve the maximum level of final goods needed for sustaining the population and for recovery as constrained by surviving plant capacity and inventories. The production by sector is then allocated by the MRL/A model to regions, constrained by plant capacities, so as to minimize transport costs in supplying inputs to plants and deliveries to final consumption by region. Region-to-region transport freight routings are an output of the model.

A prototype version of this model was applied to a 35-sector, 20-region problem, involving approximately 600 constraints and 5,000 variables (3). As a result of this exercise it was estimated that an 80-sector, 50-region problem would be manageable. In order to obtain finer area detail (e.g., counties or BEA areas), the practical solution appears to be to separate the model into two stages: the first stage would encompass an optimization of the regional breakdowns to the state level; the second stage would optimize location by counties or BEA areas within states.

This model has promise for both civil preparedness applications and for general transportation planning analysis. However, the linear programming optimization is very costly in computer time and also has questionable reliability unless the transportation links, modal transfer facilities and interconnections are finely represented in the coefficients in the model. Otherwise many physical and institutional factors are overlooked which negate the validity of the transportation routings generated by the model. This type of improvement is very likely to increase the complexity of the model to the point that it may not be practical.

There is much to be said for feasibility type models which do not optimize but which may reflect actual conditions much closer than optimizing models. These models can deal in much more structural detail within the same computational constraints. Although they

necessarily have to depend upon past relationships for quantification, the greater structural detail makes these relationships more reliable for the future than otherwise would be the case. There is a definite tradeoff between model elegance and detail; judicious compromises may be the best answer.

A feasibility type interregional input-output model system is described in the next section.

### Interregional Input-Output Model System

This model system would consist of an interregional input-output model with transportation activities as described in Chapter 1, with sub-models to break down further regional detail within the first hierarchy of regional detail. Transportation freight activity could be generated inside the model and sub-models as described in Chapter 1, or handled outside the model and iterated with the economic model as described at the beginning of this chapter. The allocation of transport freight flows to routes in a separate model would obviate the use of past patterns of transport flows and would be vital to many transportation planning and analysis applications.

A feature of this model, not necessarily unique to it, is that the first hierarchy of regional detail can be implemented apart from the second level of detail. Regional planning groups could each construct their own model with inter-area detail within the region and link it to the comprehensive interregional model, regardless of progress made on similar models for other regions.

Current work by Jack Faucett Associates for the Transportation Systems Center, U.S. Department of Transportation, is encouraging as to the feasibility of constructing an interregional input-output model with BEA regional detail. One of the most difficult data problems is the development of freight commodity flows between the regions in an interregional input-output model. These flows are needed to reflect the regional interdependencies in the model which generate the freight flows which are the grist for the transportation analysis. In the current work, considerable headway has been made in developing and reconciling freight flows for bulk commodities with production (supply) and



consumption (disposition) estimates by BEA region. These flows and associated reconciliations are being developed for the bulk commodities listed in Table 1. These bulk commodities account for over 75 percent of intercity freight flows as shown in the tabulation. The data development has been nearly completed for one-half of these commodities at this time with a good degree of success in inferring the transport flows missing from the available data so as to approximately balance the supply and disposition by BEA mode. The data for the other commodities will be completed in the near future.

The point of this discussion is that it appears feasible to construct these data at the BEA regional level. Since transportation freight flows are highly concentrated in a limited number of relatively homogeneous commodity groups, very detailed work on these commodity flows can be afforded. The other commodity groups, accounting for less than 25 percent of total intercity tonnage, are much more difficult due to the heterogeneous commodities included; however, more approximate estimates may be used due to their lesser importance.

The work described above has also yielded many insights into the feasibility of developing the basic input-output transactions data at the BEA regional level of detail. It now appears that a reasonably good data base could be developed using various estimating methodologies for filling in the data gaps.

This leads to a conclusion that the BEA regional detail is appropriate and achievable in the interregional input-output model. This is deemed to be a much more satisfactory regional unit than states for economic analysis since it is based on measures of economic affinity which do not recognize state boundaries. Output from this model would include production and consumption by BEA region and transport freight flows between BEA regions. This output would then become input to the BEA sub-models which would then calculate similar detail for counties or for any defined sub-areas within the BEA region.

TABLE 1  
INTERCITY FREIGHT, 1972  
PRINCIPAL BULK COMMODITIES  
(Millions of Short Tons)

Commodity	Rail	Water	ICC Regulated Truck	Pipeline <sup>a</sup>	Total	Percent
Corn	33.3	16.4	.2		49.9	1.34
Wheat	44.8	7.8	.4		53.0	1.42
Soybeans	10.6	9.0	.2		19.8	0.53
Marine shells	.3	18.2	.1		18.6	0.49
Iron and manganese ores	90.9	74.6	.1		165.6	4.44
Copper Ores	10.4	--	--		10.4	0.27
Anthracite	3.8	{ --	.1		3.9	0.10
Bituminous and lignite	371.1		.3		520.4	13.99
Crude petroleum	1.0	103.7	3.0	487.9	595.6	16.02
Crushed and broken stone and sand and gravel	110.5	112.4	4.9		227.8	6.12
Phosphate rock	36.4	8.8	.6		45.8	1.22
Logs, pulpwood, etc.	75.1	21.2	2.0		98.3	2.63
Lumber, etc.	19.5	2.1	2.3		23.9	0.64
Pulp, paper and paperboard	35.0	2.3	6.4		43.7	1.17
Jet fuel	.2	13.2	{ --	32.2	45.6	1.22
Gasoline	1.2	93.6		211.9	367.2	9.88
Distillate fuel oil	1.1	85.3	20.7	99.8	206.9	5.55
Residual fuel oil	5.9	102.2	9.8		117.9	3.16
Cement	21.3	10.6	14.6		46.5	1.24
Iron and steel	50.5	7.5	24.3		82.3	2.21
Motor vehicles and parts	28.0	.6	28.4		57.0	1.53
Metal scrap	31.9	1.7	.7		34.3	0.92
All other commodities	465.1	146.6	277.6		889.3	23.91
TOTAL	1,447.9	986.8	457.2	831.8	3,723.7	100.0

<sup>a</sup>Source: Minerals Yearbook 1972, entering into pipelines.

<sup>b</sup>Small amount may be Anthracite.

<sup>c</sup>Small amount may be Jet fuel.





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